MAD 11/96

rev. GDM 11/30/01 & 11/18/02

Experiment 9 – Resonance of Air Columns

Objective

To measure the speed of sound using a phenomenon known as resonance.

Equipment

- Resonance tube apparatus.
- Tuning forks.
- Rubber hammer.
- Thermometer.
- Dixie cups (to collect excess water).

Theory

A general property of waves is that the speed of the wave is equal to its frequency multiplied by its wavelength:

$$v = f\lambda. \tag{1}$$

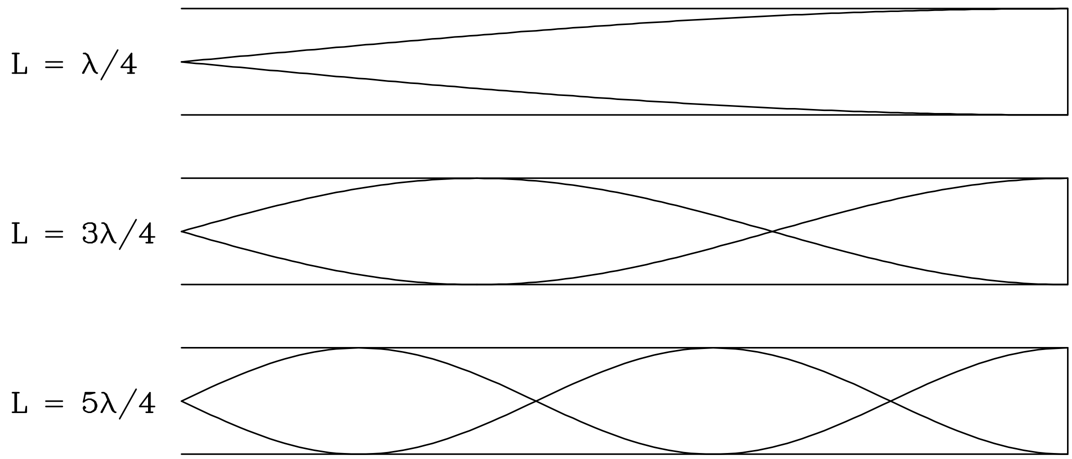
Tuning forks are designed to vibrate as a specific frequency, independent of the density and pressure of the gas surrounding them. Therefore, if we measure the wavelength of the sound produced by a tuning fork, we may use its known frequency to determine the speed of sound.

Air can transmit sound waves of all frequencies, but a column of air, with a well-defined length, will vibrate especially well for a certain set of wavelengths. For these special wavelengths, the reflected wave and the incident wave at each end of the column add in phase, giving resonant standing waves. This principle is employed in many musical instruments, such as pipe organs, trumpets, clarinets, flutes, etc.

The air column we will be using in this experiment is open to the atmosphere at one end, but closed (*i.e.* it is filled with water) at the other. This is generally referred to as an open-closed pipe. The open end of the column, being in direct contact with the outside atmosphere, is always at atmospheric pressure. Therefore, any standing wave in the column will have a pressure node at the end: the pressure does not change at that point. The closed end of the column can have any pressure whatsoever. To form standing waves this end must be an anti-node: that is, the variation in pressure is largest at this point. These considerations lead to the series of standing waves illustrated at the top of the next page.

Resonance will occur when the length of the column (L) is an odd-half integer number of quarter wavelengths:

$$L = \tfrac{1}{4}\lambda,\ \ \tfrac{3}{4}\lambda,\ \ \tfrac{5}{4}\lambda, \ldots \tag{2}$$



In this experiment, we will measure the first three values of L for which resonance occurs for a given tuning fork. By inverting Eq. (2), we may use these lengths to obtain three measurements of the wavelength of the sound produced by the tuning fork. Combining these measured wavelengths with the known frequency of the fork, we may compute the speed of sound.

The speed of sound in air is 331.4 m/s at 0°C. The speed of sound does depend somewhat on temperature. An approximate relation is

$$v = 331.4 \text{ m/s} + T * 0.6 \text{ m/s}\cdot{}^\circ\text{C} \qquad (3)$$

where the temperature T is to be measured on the Celsius scale.

Procedure

1. Raise the water supply tank until the tube is nearly full of water.

2. Begin with the higher-frequency tuning fork. Determine the shortest tube length for which resonance is heard. Hold the tuning fork just above the tube with the prongs oriented so that they vibrate vertically, and strike it with the rubber hammer. Slowly lower the water level while listening for a sudden increase in the sound volume: this is resonance. Once you've found the approximate resonance length, change the water level around that point very slowly, listening for the maximum volume of the sound. Record the length of the column at the resonant point. You and your partner should work together here, since it is hard to have an ear to the tube and an eye on the water level simultaneously! Repeat the measurement of the resonant length three times (for a total of four trials). Average the readings. Record the frequency of the tuning fork.

3. Repeat step **2**, but for the next two longest tube lengths for which resonance is heard. You should slowly increase the length of the column until resonance is heard, but you may use the information in the Theory section to help determine where to start searching.

Tuning Fork #1: $f =$ ____________

	first resonance $L = \frac{1}{4}\lambda$	second resonance $L = \frac{3}{4}\lambda$	third resonance $L = \frac{5}{4}\lambda$
trial 1			
trial 2			
trial 3			
trial 4			
average value of L			
wavelength λ			
speed of sound v			

Tuning Fork #2: $f =$ ____________

	first resonance $L = \frac{1}{4}\lambda$	second resonance $L = \frac{3}{4}\lambda$	third resonance $L = \frac{5}{4}\lambda$
trial 1			
trial 2			
trial 3			
trial 4			
average value of L			
wavelength λ			
speed of sound v			

4. Repeat steps **2** and **3** for the lower-frequency tuning fork. You should find the approximate resonance position by slowly varying the water level in the tube, but you may use the information in the Theory section to help determine where to start searching. **Note:** The water supply tanks are just a bit too small. You will need to use the Dixie cup to remove some of the water to make the air column long enough to find the third resonance using the lower-frequency tuning fork (and possibly for the second resonance as well).

5. Record the temperature of the room.

Temperature of the room	

Analysis and Questions

1. For each resonant length, determine the wavelength of the sound. Using the known frequency of the tuning fork, determine the speed of sound.

2. From the temperature of the room and Eq. (3), determine the expected value of the speed of sound:

3. How well do your measurements agree with the expected value? Do any of the measurements deviate significantly from the others?

Average your 4 or 5 best measurements (that is, the 4 or 5 which agree most closely with each other) and compare the result to the expected value. (Report the difference as a percentage).

4. Describe briefly how you could use the same apparatus to determine the frequency of an unknown tuning fork.

5. Estimate the range of tuning forks which could be used with this apparatus. Assume that you want to be able to find at least the first two resonances. Furthermore, assume that it's too difficult to make the air column shorter than about 5 cm, since the clamp holding the tube in place prevents you from raising the supply tank high enough.